Motion Prediction for Watercraft Operations and Recovery

Zhiliang Xing, Lt. Brook Sherman, Leigh McCue

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Brief history & motivation (from the sea-based aviation perspective)

Historical data taken from Lt. Brook Sherman's MS Thesis "The Examination and Evaluation of Dynamic Ship Quiescence Prediction and Detection Methods for Application in the Ship-Helicopter Dynamic Interface," 2007

Table 1- Timeline of Naval Helicopter Operations and DI Advancements

Year	Author	Effort
1903	Wright Brothers	First powered aircraft flight
1911	Eugene Ely (Carico 2004)	First fixed wing shipboard landing
1930s	US Navy (Carico 2004)	Autogyro experiments on ships
1943	US Army (Carico 2004)	First Helicopter Shipboard Landing
1949	US Navy (Carico 2004)	Rotary Wing Branch established at Naval Air Test Center (NATC)

Year	Author	Effort
1960		
62	US Navy (Kolwey and Coumatos 1975)	Initial effort to define marking/lighting for night ops
65	(Dalzell 1965)	Suggests possible predictions for carriers
65	(Durand and Wasicko 1965)	Analysis of Carrier Landing
69	US Navy (Kolwey and Coumatos 1975)	Visual Landing Aids bulletin established first standard lighting and aviation facility standards for non-aviation ships
69	(Kaplan 1969)	Wiener prediction for aircraft carrier (pitch)

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Year	Author	Effort
1970		
70	US Navy (Kolwey and Coumatos 1975)	Light Airborne Multi-Purpose System (LAMPS) Program elevated to High Priority
71	US Navy (Beck 1976)	Dynamic Interface test program launched
71-73	US Navy (Kolwey and Coumatos 1975)	Glideslope, line up lights, floodlights and deck markings evaluated
71-73	US Navy (Baitis and Woolaver 1975)	First Comprehensive shipboard VSTOL Aircraft testing includes recommendation for motion prediction program
73	US Navy (Kolwey and Coumatos 1975)	Defined certification process for shipboard decks
74	(Gold 1974)	Visual Perception of Pilots in Carrier Landings
75	(Tuttle 1975)	Report on improvements to H-2 Helicopter for small ship operations
75	(Kolwey and Coumatos 1975)	Report from 1974 USS Bowen/SH-2F testing
75	US Navy (Baitis 1975)	Study of the influence of ship motions on flight operations (SH-2 and DE-1052 Destroyer)
76	(Beck 1976)	Motivates flight testing for safe operating envelopes
77	(Olson 1977)	Suggests Seakeeping analysis WRT VSTOL as a design consideration for ships
77	(Garnett and Davis 1977)	Reports on the use of a Wind tunnel and smoke flow testing to examine DI
77	(Weiss and DeVries 1977)	Design of a ship motion measurement filter (Kalman Filter)

Sherman, 2007

Brief history & motivation (from the sea-based aviation perspective)

Year	Author	Effort
1980		
81	(Yumori 1981)	Develops an ARMA/Kalman filter prediction package for Amplitude and Phase
82	(Comstock, Bales et al. 1982)	Examine ship flight deck performance for various aircraft
82	(Triantafyllou and Bodson 1982)	Prediction of ship's motion (w/in 25%) for 5s and up to 10s for roll using Kalman Filter approach
83	(Triantafyllou, Bodson et al. 1983)	Modeling Motions
83	(Sidar and Doolin 1983)	Carrier/aircraft longitudinal landing predictions (Kalman filtering)
84	(Paulk and Phatak 1984)	Lull/Swell binary index, good for confirming pilot's intuitions
85	(Brown 1985)	Quantifies cost of lost operations due to ship motions
85	(McCreight and Stahl 1985)	Predicts ship percent time of operation (PTO) and Limiting Significant Wave Height (LSWH)
85	(Bodson and Athans 1985)	Developed control to chase deck motions, pilot controls vertical descent (Kalman Filtering)
86	(Healey 1986)	Suggests simulation of DI for inexpensive results
87	(O'Reilly 1987)	The first motion index, EI indicates energy levels of the flight deck

Sherman, 2007

Brief history & motivation
(from the sea-based aviation perspective)

Year	Author	Effort
1990		
91	(Negrin, Grunwald et al. 1991)	Studies the benefit of inertial stable visual cues on pilot hover ability
91	(Berbaum, Kennedy et al. 1991)	Study of helicopter shipboard landing tasking levels in approach phases
92	(Lainiotis, Charalampous et al. 1992).	Presented improved ALF filter employing multiple Kalman Filters
93	(Lainiotis, Plataniotis et al. 1993)	Used ALF filtering for neural network approach to prediction
98	(Burton, deKat et al. 1998)	FREDYN introduced for motion analysis and simulation
98	(Broome and Hall 1998)	Introduces another ARMA Model for roll motions
98	(Ferrier and Manning 1998)	Simulation and Testing of the LPD Helicopter Recovery Aid
98	(Ferrier 1998).	LPD in High Sea States
98	(Ferrier, Langlois et al. 1998)	Design and Test of Automated UAV/VTOL Shipboard Recovery System
99	(Lumsden, Padfield et al. 1999)	Human Factors Challenges at the Helicopter Ship Dynamic Interface

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Brief history & motivation (from the sea-based aviation perspective)

Year	Author	Effort
2000		
00	(Fleischmann 2000)	US Patent for a LPI using a mast mounted range-measuring sensor
00	(Ferrier, Baitis et al. 2000)	Evolution of the LPD for Shipboard Air Operations
00	(Ferrier, Applebee et al. 2000)	LPD Visual Helicopter Recovery Aide; Theory and Real Time Application
01	(Gallagher and Scaperda 2001)	MSI, tipping/sliding index for commercial use
01	(Ferrier, Bradley et al. 2001)	LPD/EI Development for Australian LPA
01	(Advani and Wilkinson 2001)	DI modeling and simulation comprehensive study, including pilot workload
02	(Colwell 2002a)	Ship/Helicopter Operating Limits (SHOLs)
02	(Gray 2002)	Safety Index based on helicopter type and MIIs
02	(Colwell 2002)	Ship Motion Criteria - Operating Challenges
03	(Lynch and Baker 2003)	Joint Venture DI (for high speed catamarans)
03	(Langlois, LaRosa et al. 2003)	Dynaface, securing system simulation program
04	(Ferrier, Baker et al. 2004)1	LPD Autoland Operations for UAV
04	(Lee and Horn 2004)	Analysis of Pilot Workload with Airwake Study
04	(Carico 2004)	Reemphasizes necessary future paths for DI
04	(Colwell 2004)	FDMS Operating Concepts and System Description
04	(USCG 2004)	MISHAP analysis firmly recommends LPI approaches for mitigation

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Brief history & motivation (from the sea-based aviation perspective)

Year	Author	Effort
05	(Ferrier, Duncan et al. 2005).	Manned Flight Simulation of LPD (Type 45/Merlin Helicopter)
05 05	(Lee, Sezer-Uzol et al. 2005) (Ford, Hardesty et al. 2005)	Continuation of Pilot Workload analysis with Airwake modeling GPS/INS ship approach
05	(Rowe, Howson et al. 2005)	Additional commercial application of MSI
05	(Ferrier, Chang et al. 2005)	LPD application to LPD 9 Class Amphib and Firescout UAV
05	IDEA	Airwake CFD work
06	(Carico and Ferrier 2006)	Simulator evaluation of LPD as a VLA on Naval combatants
07	(Descleves 2007)	Tactical use of weather combined with ship motion predictions

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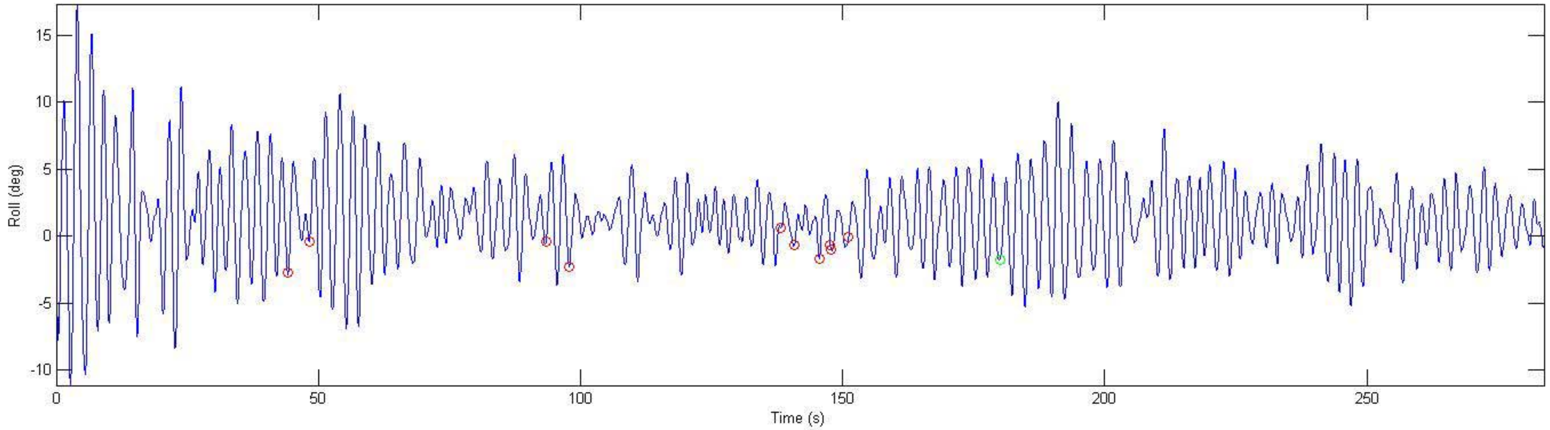
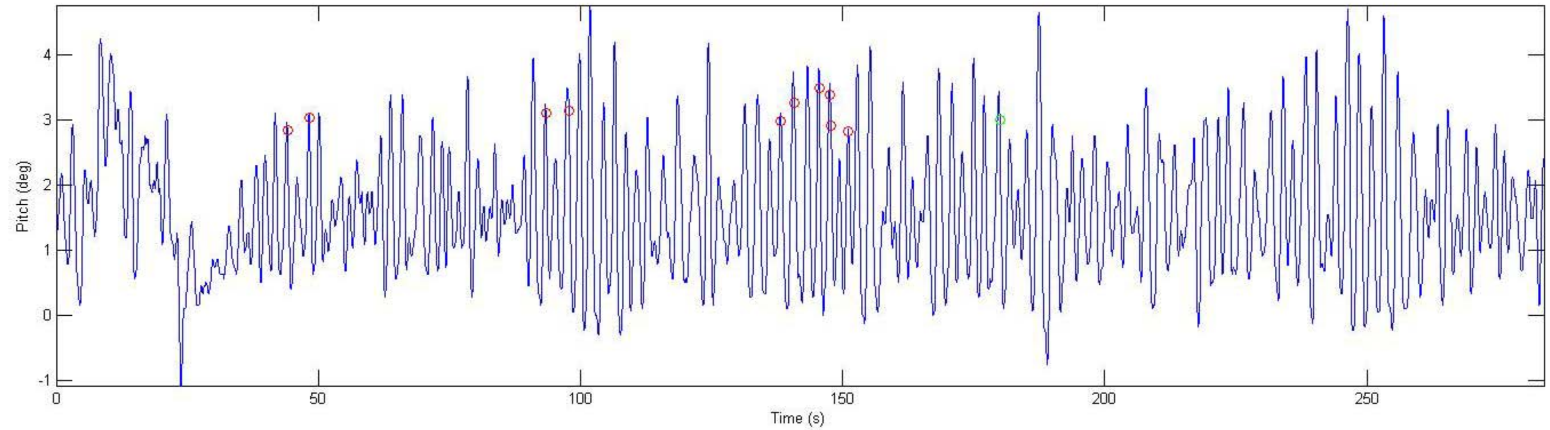
Simple probabilistic approach

- Input roll, pitch, roll velocity, and pitch velocity past time history (or whatever relevant variables characterize the system) and non-dimensionalize with each variables standard deviation.
- Search non-dimensional past time history for *n* neighbours nearest to the point of interest (point of interest being the time from which we wish to approximate forward, and *n* for this work was selected as 10).
- Note the actual dimensional roll, pitch, roll velocity and pitch velocity trajectories for the duration of interest immediately following each of the 10 nearest neighbours.
- Generate 1, 2, and 3 standard deviation (1, 2, 3σ) envelope curves of predicted motions based upon the mean value ±1, 2, 3σ at each time step from the neighbour time histories.

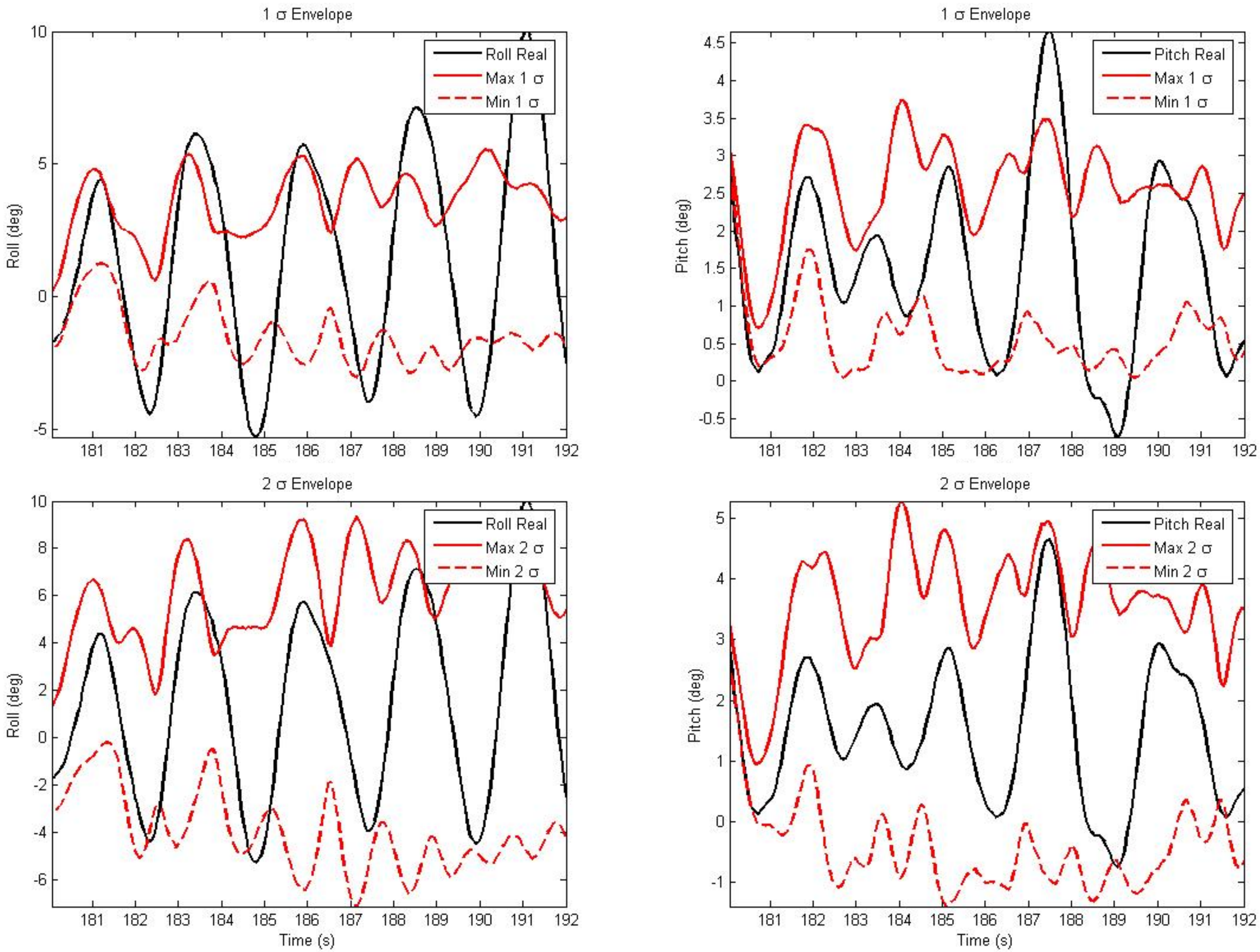
Illustration of concept

$$\| \left\langle \phi/\sigma_{\phi}, \theta/\sigma_{\theta}, \dot{\phi}/\sigma_{\dot{\phi}}, \dot{\theta}/\sigma_{\dot{\theta}} \right\rangle_i - \left\langle \phi/\sigma_{\phi}, \theta/\sigma_{\theta}, \dot{\phi}/\sigma_{\dot{\phi}}, \dot{\theta}/\sigma_{\dot{\theta}} \right\rangle_j \| < \varepsilon$$





Example: Simple statistical model, based on pitch, roll, pitch velocity, and roll velocity data.



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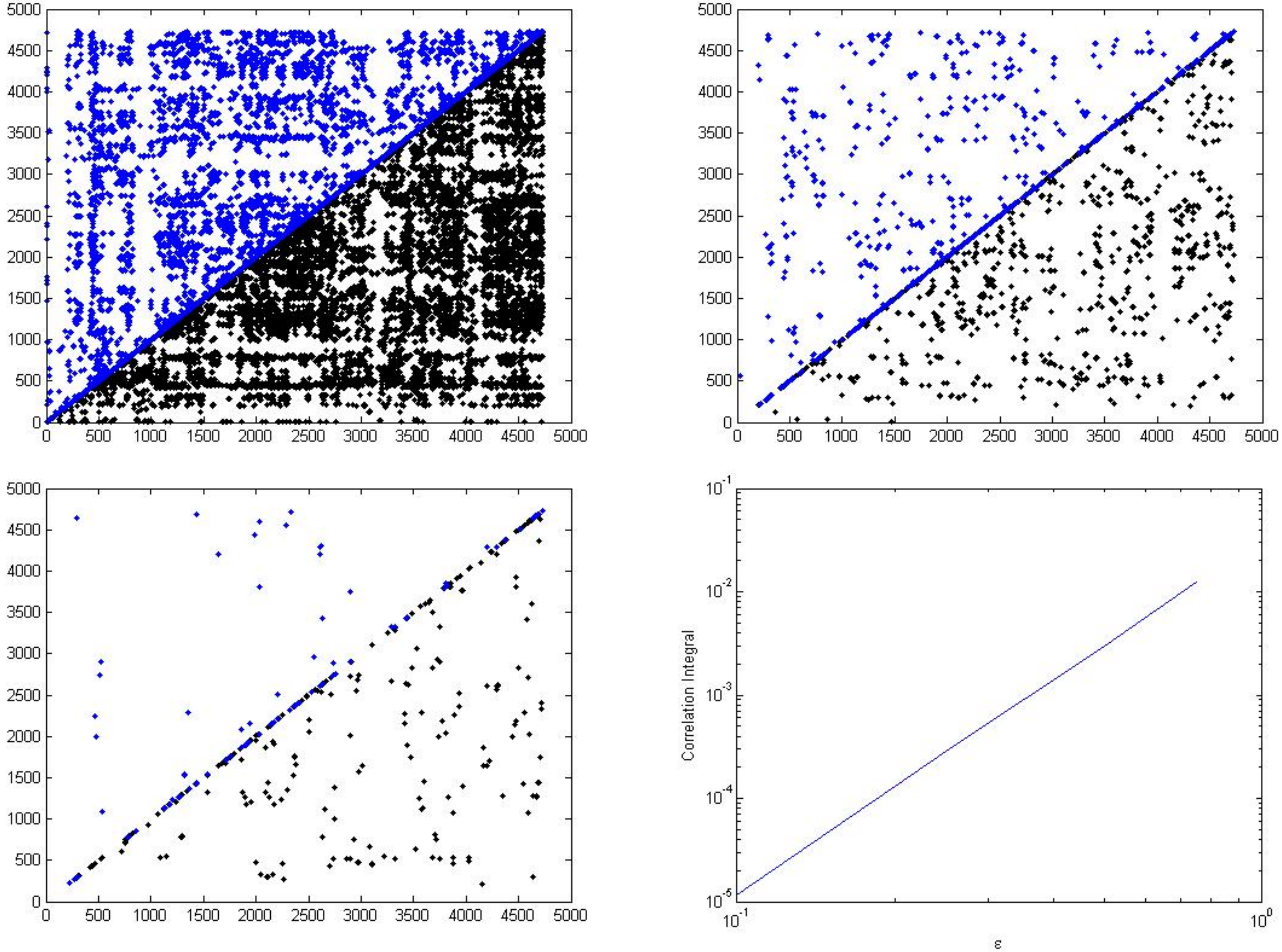
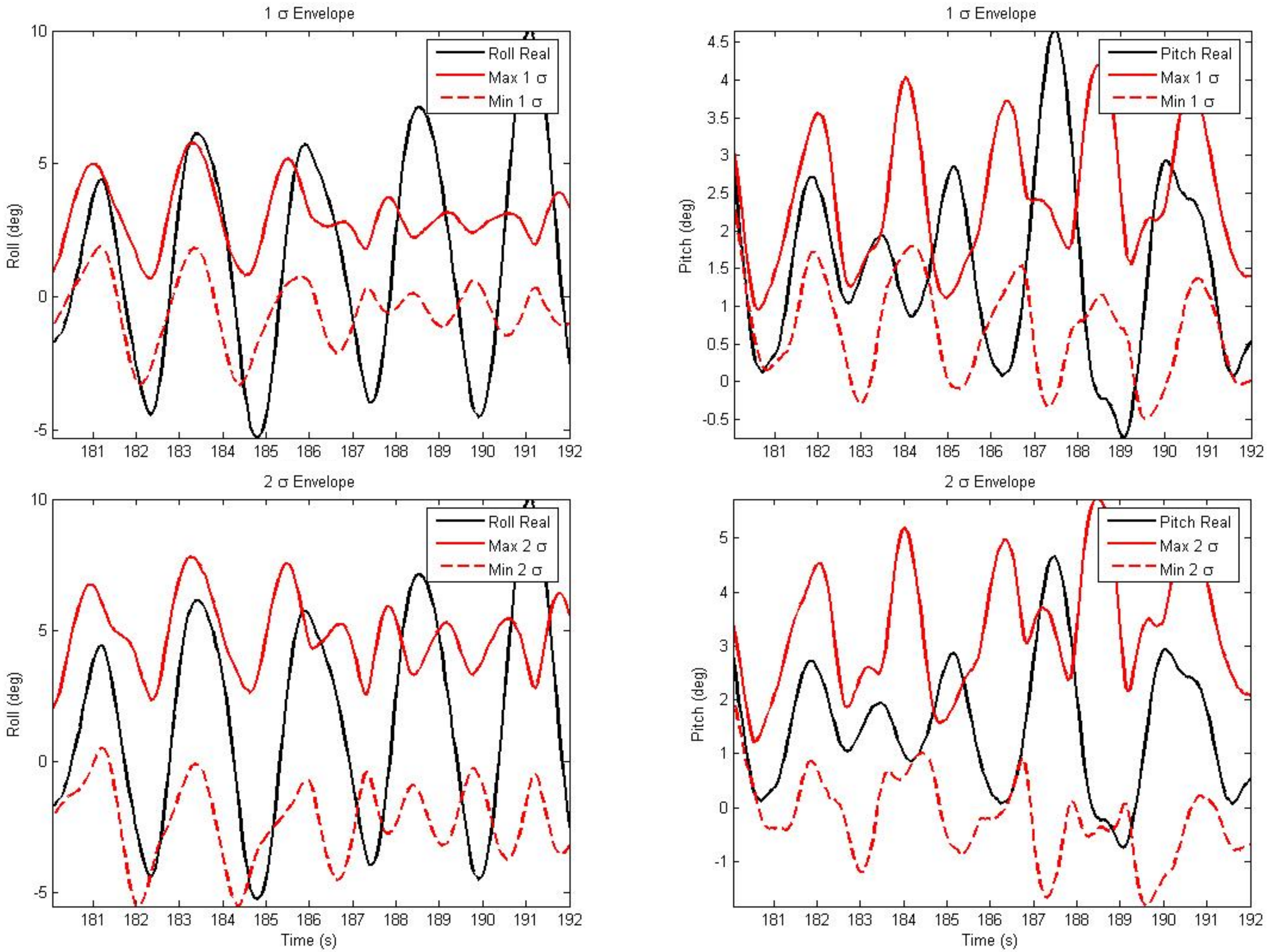
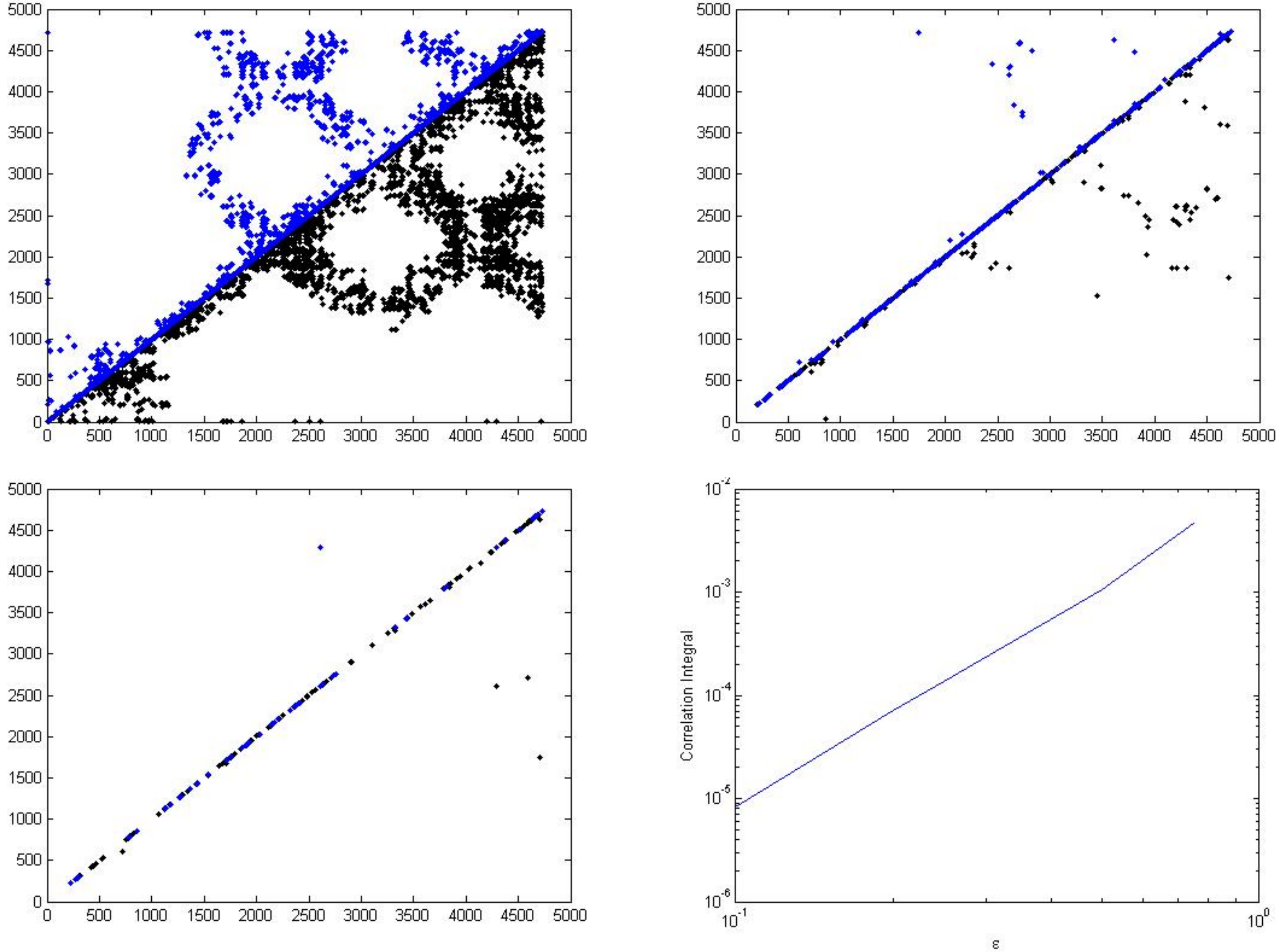


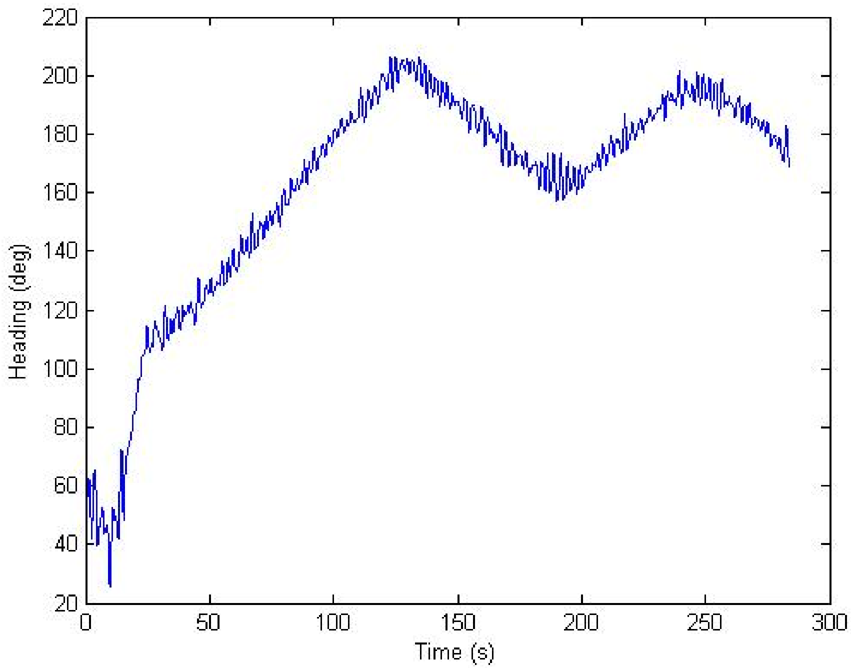
Example: Simple statistical model, based on heading, pitch, roll, pitch velocity, and roll velocity data.



Example: Simple statistical model, based on heading, pitch, roll, pitch velocity, and roll velocity data.



Example: Simple statistical model, based on heading, pitch, roll, pitch velocity, and roll velocity data.



If we knew heading data relative to waves, we could make use of this information and concatenate time histories—perhaps improving accuracy, and emulating the types of large time histories you would have in a realistic environment.

Neural Network Approach

- Assume a form for the equations of motion
- Use neural network for parameter identification problem
- Nontraditional implementation
  - We are seeking physical coefficients rather than a 'black box' form of model.
  - As such, we are using a relatively short time period as 'training data' then using that information for forward prediction.
- Future work to involve neural network for system identification as well...

Modeling

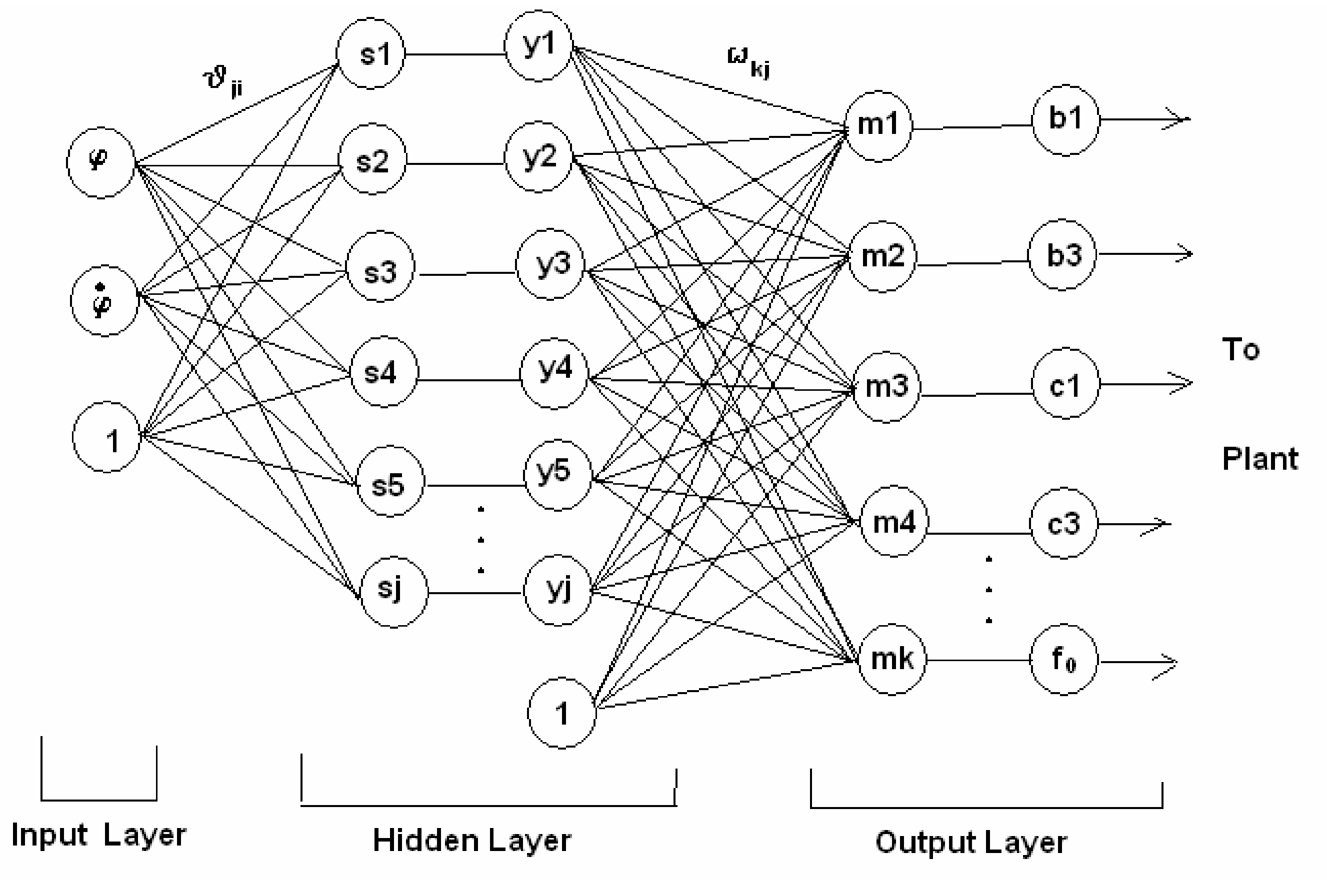
- **Traditional 1DOF roll model**

$$\ddot{y} + b_1\dot{y} + b_3\dot{y}^3 + c_1 y + c_3 y^3 = F\sin\left(\omega_e t + \phi_0\right) + F_0$$

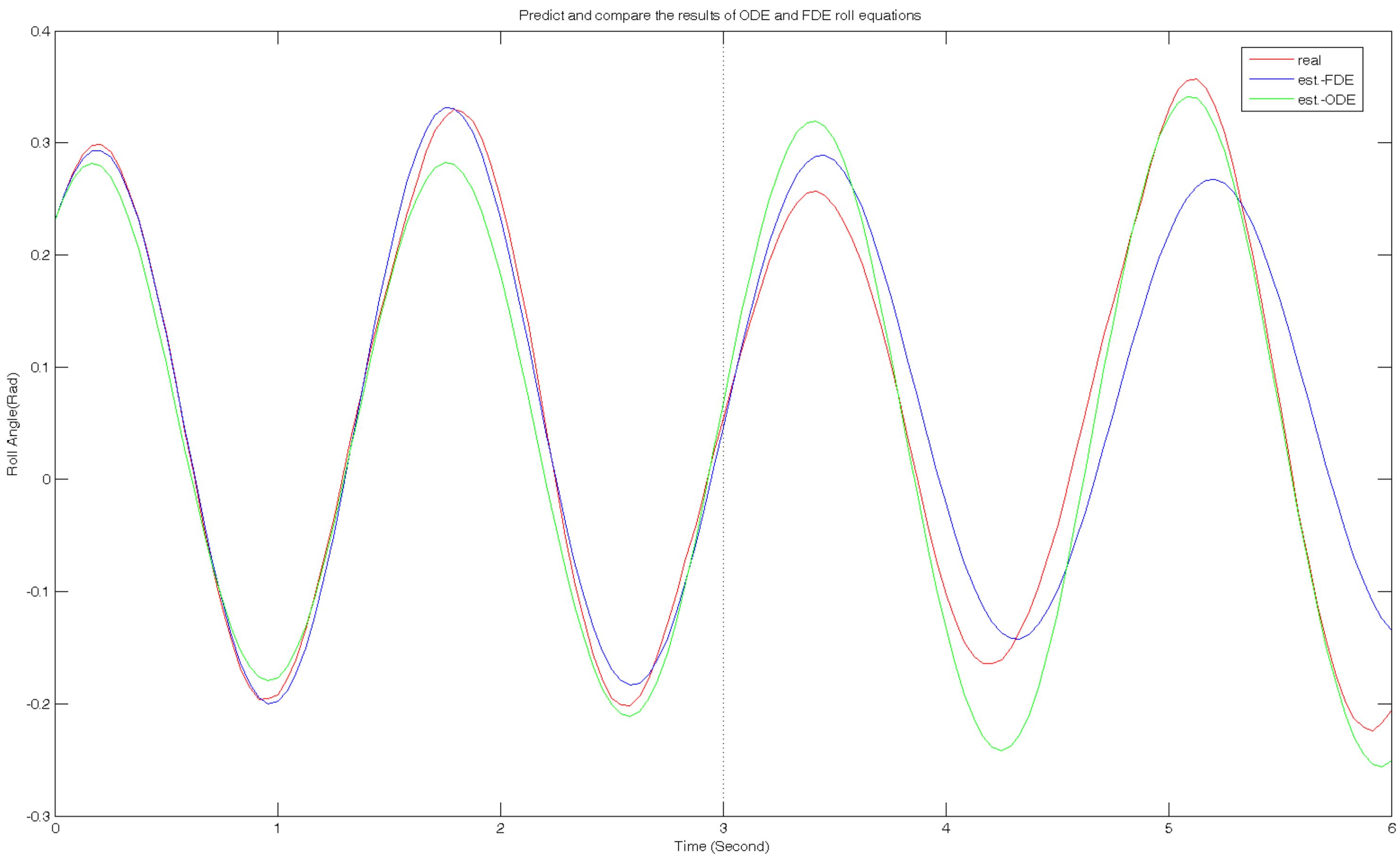
- **Nontraditional fractional derivative model (Spyrou, 2008)**

$$\ddot{\varphi} + b\varphi^{(a)} + c_1\varphi + c_3\varphi^3 = F\sin(\omega_e t + \phi_0) + F_0$$

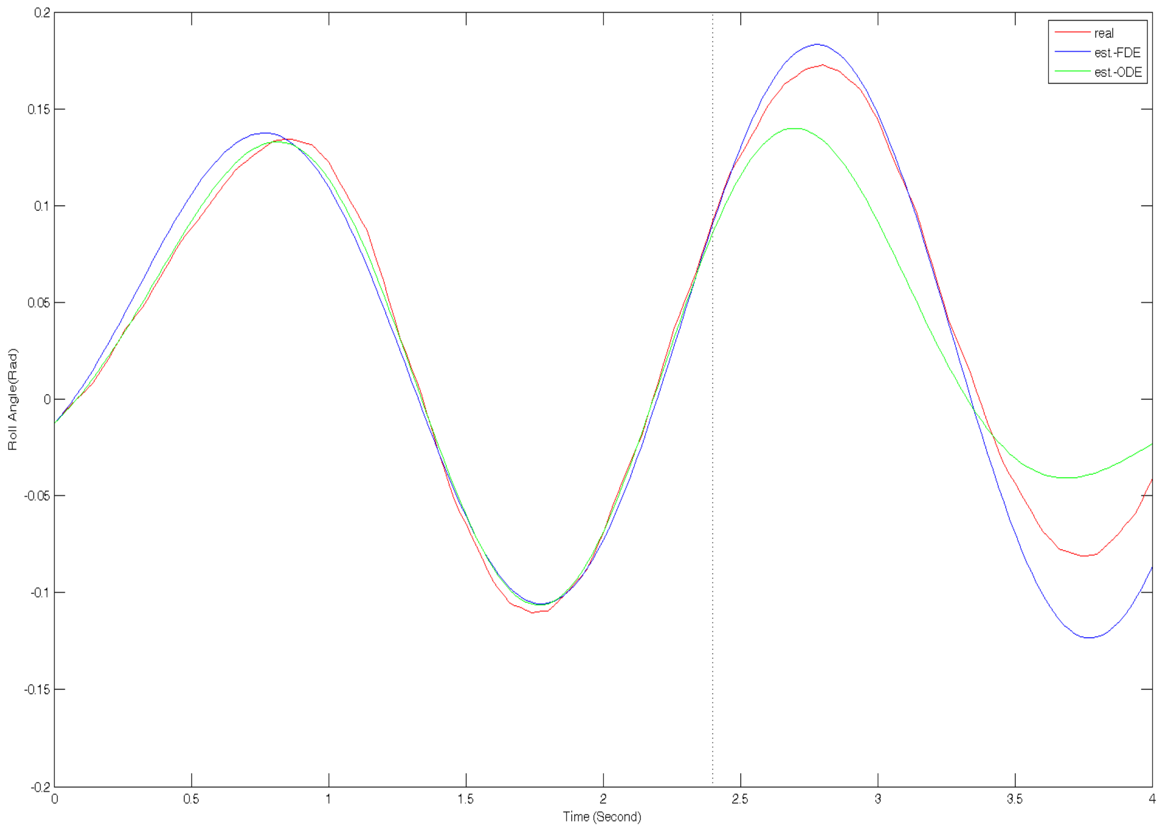
Architecture of Back Propagation-Based Neural Network Controllers

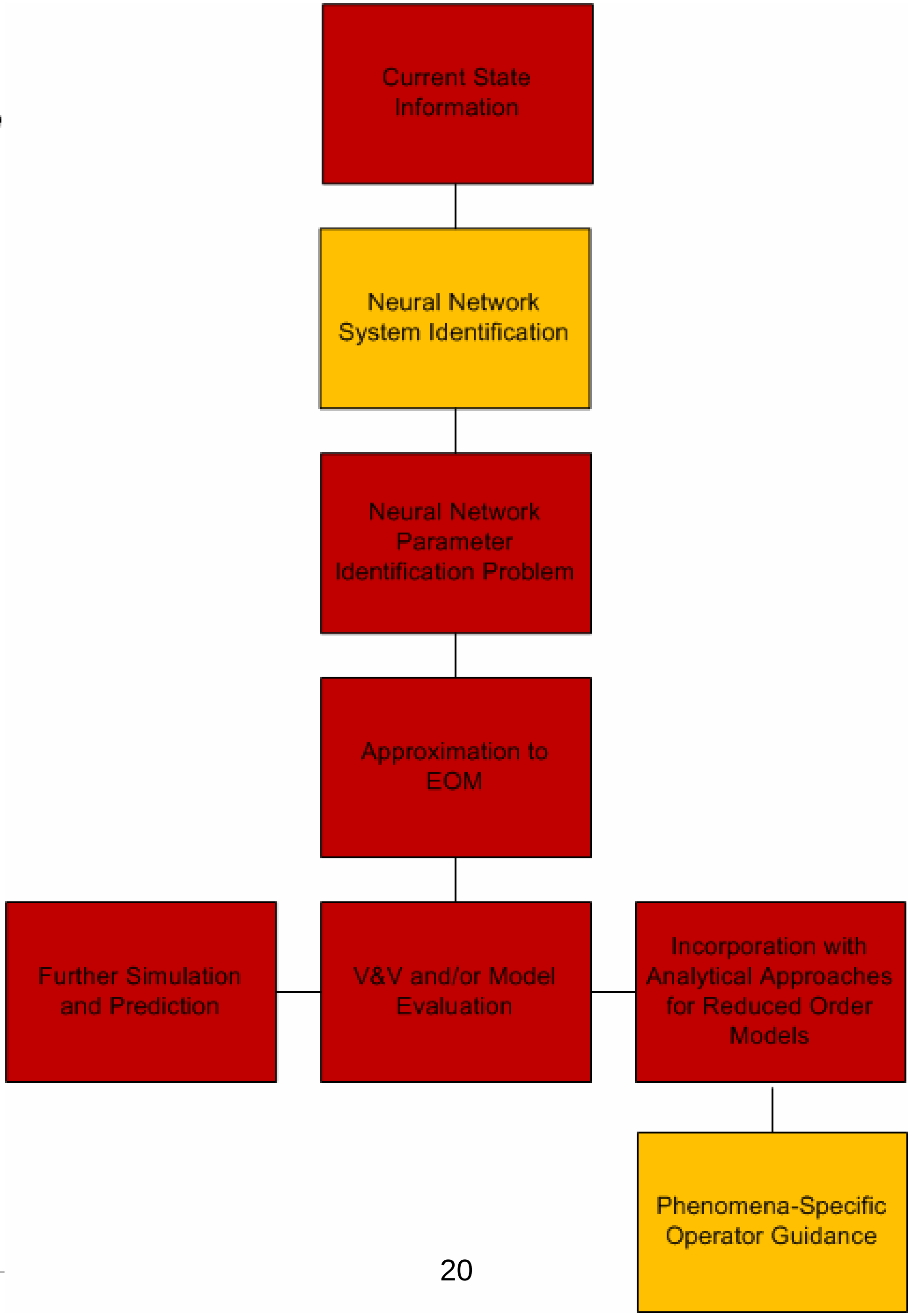


Sample result: Hull5514_data2_M0390EU



Application to the unmanned watercraft data set, excerpt from data1 file




Current State Information
Neural Network System Identification
Neural Network Parameter Identification Problem
Approximation to EOM
Further Simulation and Prediction
V&V and/or Model Evaluation
Incorporation with Analytical Approaches for Reduced Order Models
Phenomena-Specific Operator Guidance

Discussion

- All these approaches are/will be limited by a lack of knowledge of oncoming waves.
- And all can be directed to focus more on whatever variables we deem most relevant.
  - Speed, wind, etc…
  - More variables carry computation time penalties

Conclusions: Statistical approach

- Assumed process deterministic to some extent—while not bad for short time periods if we capture the right information, all it takes is one wave for the prediction to be thrown off, therefore any contol system using this information must be stochastic and able to account for these uncertainties

Conclusions: Neural Network

- The parameters in the equation of rolling motion are estimated using the roll response only. A priori knowledge of the input is not needed. This makes this method appealing for use on ships at sea for estimating equivalent instantaneous parameter values.
- Current work is looking at a host of models, single and multi-DOF, and perhaps coupling with a neural network to determine an ideal reduced order model to fit the current vessel motion conditions.
- All the parameters in the equation of motion can be estimated using this method. This may be of use when attempting to glean physical insight from the actual vessel motions which can then carry over into development of more complicated simulation tools or coupling to analytical tools.
- Different models for ship motion can be evaluated using this approach as demonstrated via comparison of a traditional ordinary differential equation model and a fractional differential equation model per Spyrou *et al* (2008).

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